

Electron Beam Lithography of HSQ and PMMA Resists and Importance of their Properties to Link the Nano World to the Micro World

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Abstract— In this work we investigated the properties of HSQ and PMMA resists focusing on contrast and line width for e-beam lithography (EBL) application. HSQ was found to be a good candidate to have desired line widths but the contrast we obtained was less than it was for PMMA. Since the fluorine based plasma does not have high selectivity over exposed HSQ, we propose a PMMA/HSQ bi-layer resist stack as a hard mask to etch Si selectively. Using this technique, 50nm deep Si fins may be patterned.

Index Terms—Electron Beam Lithography, HSQ, PMMA, Silicon, FinFET

I. INTRODUCTION

For developing and fabricating novel MOS devices such as finFETs [1], in our laboratory e-beam lithography (EBL) with resist resolutions in the range of 20 nm is required. The type of resist and processing scheme play an important role to obtain these critical dimensions. Although the inorganic negative resist called Hydrogen-silsequioxane (HSQ) [2] was first developed as a floatable insulating layer for CMOS, it is presently the mostly studied resist in EBL applications offering these aggressive dimensions.

One important advantage of HSQ is its property of transformation to silicon dioxide (SiO_2) at elevated temperatures which makes it an etch mask for Si with suitable etching conditions [3, 4]. So far, the research done on HSQ has been concentrating on parameters like baking temperature, aging, development time and temperature [5-7]. However, each parameter should be modified depending on the specific application and process conditions. Although it can serve the needs for aggressive dimensions, since the EBL writing time is relatively long and nanometer dimensions are not required for all masks in our laboratory, there is a need to link the “nano world” to the “micro world” on the same chip. Therefore, it is essential to combine the (conventional) photolithography (PL) with EBL. The integration of these two

techniques is an issue regarding the accuracy of the alignment. In this work, HSQ as well as PMMA resist properties were investigated as an EBL resist focusing on the contrast and linewidth, which are important for multi step lithography and for our desired finFET structures. Further study was done on the HSQ/PMMA bilayer resist stack to use PMMA layer as a second hard mask below HSQ, which is relatively easy to remove and has compatibility with CMOS processing compared to metal masks such as Cr. Although PMMA alone cannot be used to form Si fins for the finFET device, this part of the study was helpful to understand its properties before using it as a second hard mask.

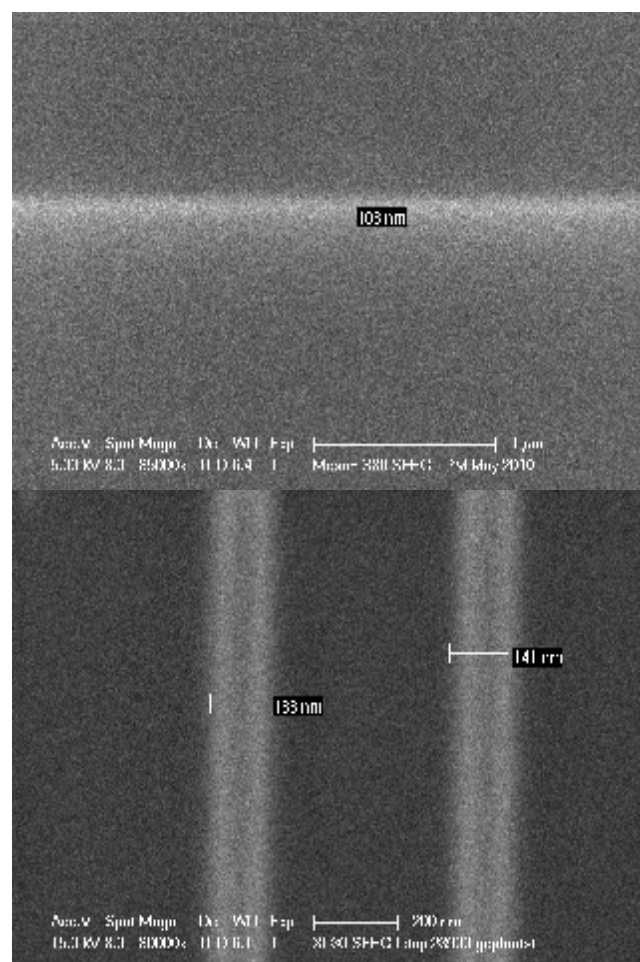


Figure 1. Lines written by EBL on HSQ (top) and PMMA (bottom) resists. Designed line widths were 100 nm.

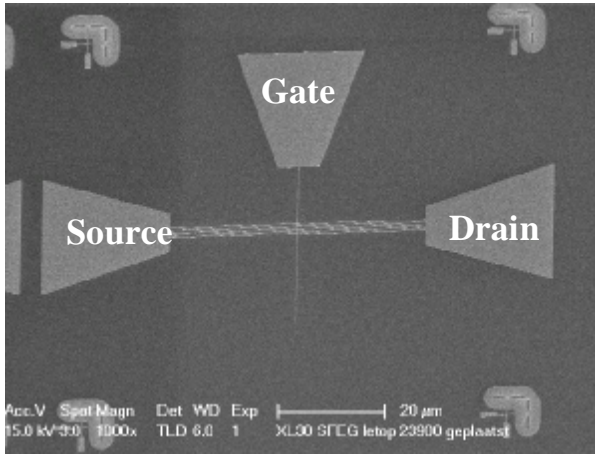
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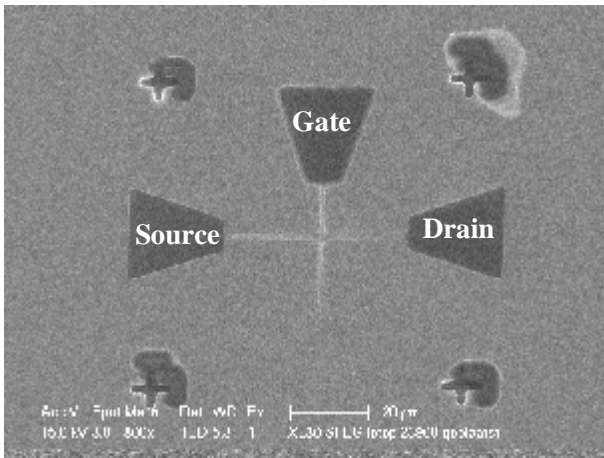
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II. EXPERIMENTAL

PL was performed to write the alignment crosses on the wafers before the EBL process. Si wafers with 400 nm SiO₂ and 50 nm poly-Si on top were used for our experiments. 1.7 micron photoresist was coated and prebaked at 95 °C for 1 min. Then, the alignment crosses were patterned on to the wafer. After post exposure bake at 120 °C for 1 min, the crosses were etched down until the Si substrate at room temperature with RIE using CHF₃ (25 sccm) and O₂ (5 sccm) at 10 mT pressure with 50 W power. Then, wafers were coated using HSQ XR1541 or A2 PMMA resists. The thicknesses of the resists were fixed during the study, being 40 nm and 100 nm respectively. HSQ was baked at 150 °C for 2 min and PMMA was baked at 160 °C for 2 min before exposure. The markers defined by PL were used to align the EBL mask with respect to the PL mask. The EBL mask mainly contains lines with line widths varying between 50 and 150 nm. We aimed to write the lines into the area defined by the PL written crosses. The beam energy was 15 keV for our EBL process. PMMA and HSQ were developed using MIBK: IPA 1:3 and TMAH for 1 min and 1.5 min respectively.



(a)



(b)

Figure 2. Structures written on (a) PMMA and (b) HSQ resists after development.

III. RESULTS AND DISCUSSIONS

Figure 1 shows the obtained (physical) line width after EBL using HSQ and PMMA resists, respectively. It is observed that designed line widths are closer to the obtained line widths by using HSQ. Although it is possible to obtain narrow structures, the contrast after both coating and development is less for HSQ than it is for PMMA. Another important property of the HSQ resist is the possibility to obtain lines down to 20 nm with our system while with PMMA the minimum obtainable line width is around 50 nm. The thickness of the resist plays an important role to achieve minimum line widths. Although a resist with a smaller thickness is desirable for obtaining thinner lines, the processing of the resist becomes more difficult due to the decrease in contrast.

PMMA and HSQ resists were used to obtain the full device structure as shown in figure 2a and 2b. The contrast becomes more important when the integration of PL with EBL should be considered. Due to the better contrast obtained with PMMA, it is easier to find the alignment crosses while applying EBL on PMMA. Therefore, the alignment accuracy was relatively high. While using HSQ on the other hand, although the contrast is not as high as we achieved with the PMMA resist, PL written structures etched down until the Si substrate were still visible after coating.

The development condition is other important parameter that can affect the size and shape of the patterned structures. The developing solution temperature is known to affect the contrast and sensitivity of the resist [7]. We did room temperature development for the HSQ and PMMA resists. Figures 2a and 2b show that PMMA could easily be removed, but HSQ could not be removed completely as it is manifested by the broadening of the gate line (Figure 3). If the wafer would be further developed, it is possible to remove the HSQ residues. However, the smaller structures would then disappear due to over development. Therefore, HSQ development parameters need to be adjusted depending on the written structure size, pitch and density.

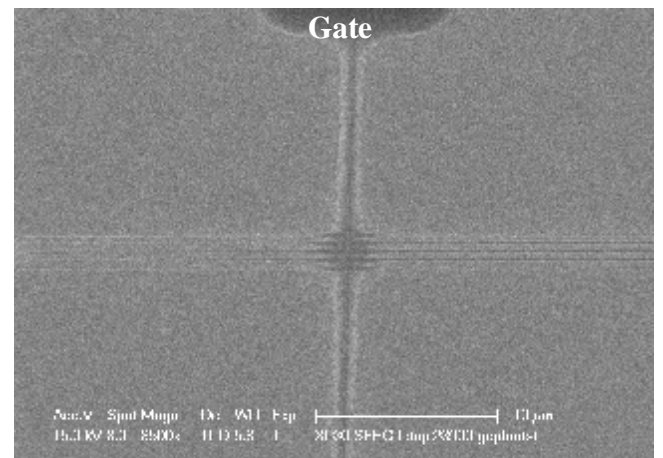


Figure 3. Closer view of fins and gate. An HSQ residue is observable near the structures.

PL to EBL alignment was done using the manual alignment markers to define the working area and then auto scanning of the smaller crosses inside the writing fields was done by the EBL system. Structures shown in figures 2a and 2b were written in EBL with automatic alignment. For the structure in figure 2a crosses were written by EBL during the first exposure while they were formed by PL for the structure in figure 2b. After investigation, it was found that the alignment accuracy became less when PL forms the crosses due to lower contrast and edge roughness. Therefore, it was not possible to align structures with more accuracy for the latter. However, experiments showed that the same accuracy could be obtained by using only the manual markers without using the auto alignment property of the device. Therefore, the last exposures were done without auto alignment (figure 4). The written structure was aligned well within the writing area for each writing field. This procedure saves total writing time by removing the scan process for the crosses. The overview of a part of the written structure can be seen in figure 5.

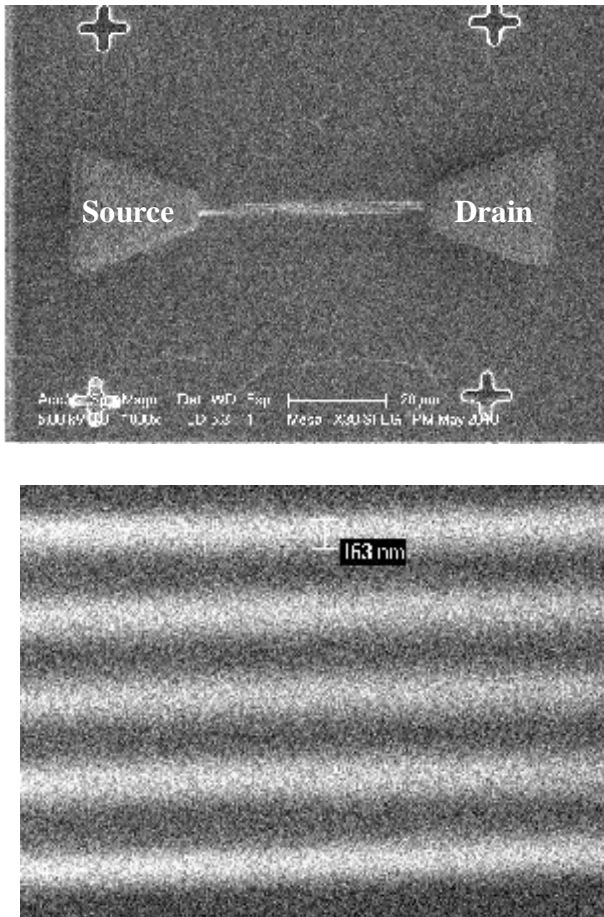


Figure 4. Structures written on the PMMA/HSQ bilayer resist after HSQ development. The figure below shows the closer view of the fins.

After EBL, RIE step was performed to obtain Si fins. Figure 6 shows a 50 nm thick and wide designed poly-Si line after poly-Si etching. Etching was done at room temperature with RIE using CHF_3 (25 sccm) and O_2 (5 sccm) at 10 mT pressure

with 50 W power. It is clear that the HSQ layer was completely gone and the original line width was decreased after etching.

It is known that HSQ becomes an SiO_2 -like layer after exposure and SiO_2 has an etch rate comparable with Si under SF_6 or CHF_3 based plasmas [3, 8]. Therefore, it is not possible to etch the Si by using only HSQ as a hard mask. The total mask layer thickness needed to be increased to protect the Si fin. In this work, PMMA was used as a second mask to transfer the line without size and shape loss. Although the PMMA under layer does not affect the contrast before writing, the contrast decreased after development of the HSQ/PMMA stack on top of the wafer as shown in figure 4. PMMA was used below HSQ in previous works for negative lift off process and to obtain various device patterns [9, 10]. However, for the first time it is used here as an etch mask. The etch chemistry mentioned above will be used for this bi-layer structure. Since PMMA is not resistant to O_2 containing plasma, another plasma recipe may need to be used to obtain the aimed device structures.

In addition to the mask used to protect the fins, effect of the structure design on etching is also observable in figure 6. The polysilicon layer on the right side is thicker due to the lower etch rate in this region caused by the scattering of the species by the neighboring line. Therefore, design of the structures also needs to be modified to have homogeneous fin structures.

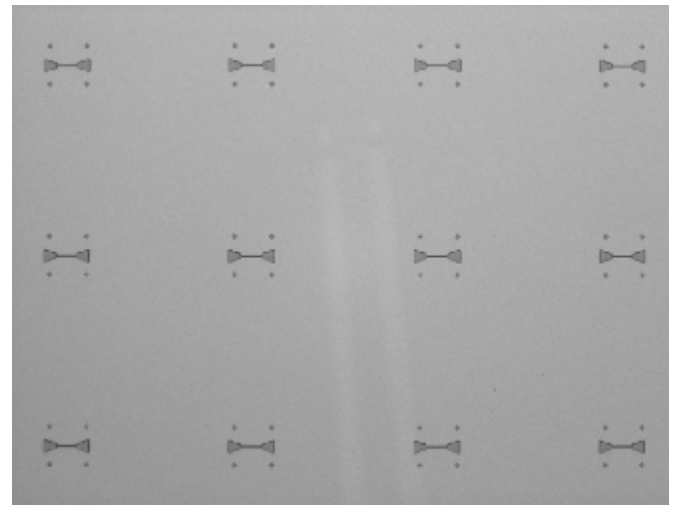


Figure 5. Microscope image of the part of EBL written structures.

IV. CONCLUSIONS AND FUTURE WORK

The results demonstrate that choice of resist is important for controlling the line width and contrast. HSQ serves the need for aggressive dimensions. Although there is a contrast lost with respect to PMMA, PL written crosses were still visible even if they were coated with HSQ. Therefore, we believe that the combination of PL with EBL was properly done. We got

In addition to EBL, etching was found to be also a very important step to have the desired structures. Unfortunately, HSQ has a high etch rate under fluorine-based plasmas. To solve this issue, a PMMA/HSQ bilayer resist stack was proposed. Different plasma etch chemistries for PMMA/HSQ bi-layer structures will be studied further in detail to obtain Si lines with designed size and straight walls, which is important for our finFET structures.

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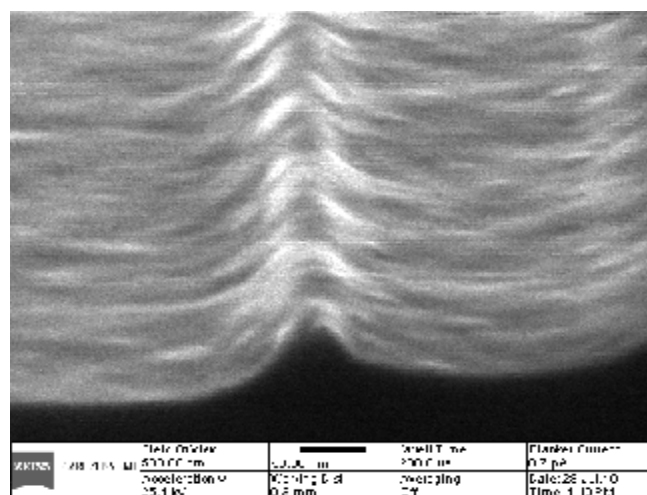


Figure 6. Poly-Si line formed after patterning and Si etching.

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